ON THE RIGHTING MOVEMENTS OF THE STARFISH.[1]

A. R. MOORE.

In an article entitled "The Behavior of the Starfish, *Asterias Forreri* de Lariol,"[2] Jennings discusses the movements of that animal in righting itself. He assumes that the starfish makes its movements in order to adapt itself to its environment and that therefore these movements are purposeful. From this assumption he concludes that "when the starfish is turned over on its dorsal surface locomotion is impossible, the finding and capture of food must stop; the delicate gills are pressed against the bottom, injuring them and impeding respiration; and displacements of the internal organs must occur that may be harmful to their proper functioning. We find, as might be anticipated, that there is a regulation of these bad effects by movement; the starfish turns again on its ventral surface."

A much simpler explanation of the righting movements has been given by Loeb.[3] He points out that the tube feet are positively stereotropic. Therefore the arms twist and turn until all of the tube feet are in a position to be in contact with a surface.

I have made observations on about thirty specimens of *Asterina miniata* and a like number of *Asterias ochracea*, with a view to determining the nature of the righting movements.

Let us look first at the causes, which Jennings has given us, for the starfish righting itself.

In regard to the first, viz., that locomotion is one of the ends which a starfish has in view in righting itself, I have found that very frequently the starfish crawls up the side of the aquarium and, upon reaching the surface of the water, thrusts out three or four arms dorsal side downward, their tube feet clinging to the surface film of the water. In such a position they remained

[1]From the Herzstein Research Laboratory, New Monterey, Cal.

[2]Jennings, *University of California Publications*, Zoology, Vol. 4, pp. 53–185.

[3]Loeb, "Comparative Physiology of the Brain," Chapter 3.

sometimes for more than an hour, although further locomotion was impossible, and no attempt at righting was made. In fact, the starfish often retained such a slight attachment to the wall of the aquarium that the surface film of the water could no longer support the weight of the animal, with the consequence that the latter fell to the bottom of the tank. In such cases the tube feet cling to the surface film of the water because the film acts as a solid surface; it cannot, however, bear the animal's weight. Romanes[1] speaks of these movements as follows: "On reaching the surface, the animal does not wish (!) to leave its native element . . . and neither does it wish (!) again to descend into the levels from which it has just ascended. It therefore begins to feel about for rocks or sea weeds at the surface, by crawling along the side of the tank and every now and then throwing back its uppermost ray or rays along the surface of the water to feel for any solid support that may be within reach." Romanes evidently was not familiar with surface tension. Had he known that the surface film of a liquid acts like a solid surface he would have been prevented from attributing intelligence to the starfish.

In order to see whether pressure on the gills might, as Jennings states, cause the starfish to turn over, I supported a glass plate in the aquarium, at a height just sufficient to press lightly on the dorsal side of a starfish moving over the floor of the tank. This was placed in the path of an approaching starfish. The latter did not change its direction when the plate was touched, but pursued its course, although the gills were pressed down. Furthermore, if a starfish is allowed to attach itself to a glass plate and is then suspended dorsal side downward so that it touches the bottom, its movements continue normally, although it could easily right itself if that were necessary. Clearly, then, pressure on the gills is not one of the factors which causes a starfish to right itself.

The displacements of the internal organs which, we are assured, "must occur" when the dorsal side is down, can only be due to gravity. I have frequently observed large numbers of starfish clinging, dorsal side downward, to overhanging ledges, feeding

[1]Romanes, "Jellyfish, Starfish and Sea Urchins," p. 268.

on barnacles and mollusks. Surely, "the displacements of the internal organs which *must* occur" when the dorsal side is downward, do not interfere in the least with the ingestion and digestion of food. Such "displacements" can, therefore, hardly be considered seriously as causes for the righting movements taking place.

We are forced to conclude, from the observations described, that, as Loeb has stated, the starfish ceases its efforts to right itself the moment all the tube feet can be brought into contact with a solid surface. Gravity plays no part in the righting movements.

The idea has been advanced by Loeb[1] that the mechanism of the righting movements is the result of coördinating and inhibiting impulses, which are transmitted to the various arms by the ventral nerve ring.

Six distinct methods of the righting reaction have been described by Jennings, but he has made no analysis of them on the basis of inhibiting and coördinating impulses. My observations agree with Loeb's assumption and give a rather simper explanation of the behavior of the starfish.

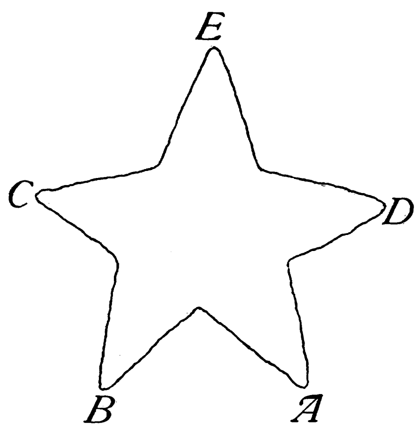

FIG. 1.

As a rule, when a starfish is placed upon its dorsal side, the arm whose tube feet first touch bottom determines the course of the righting. This arm begins at its distal end to twist the

[1]Loeb, "Comparative Physiology of the Brain," Chapter 3.

dorsal side upward, and as rapidly as the twisting is accomplished the tube feet secure a hold on the bottom. Next, if not simultaneously, the arm adjacent to the ventral side of the arm which is obtaining a hold, twists, so that the ventral surfaces of the two arms face each other, and secures itself in the same manner as the first. If *A* and *B* have in this way attached themselves to the bottom, inhibiting impulses are sent to *C* and *D*. The latter release themselves if they have already seized the bottom, rise ventrally, dragging *E* which either remains passive or bends dorsally, even catching the bottom with its tube feet in some cases. The righting is completed by *C*, *D* and *E* passing over *A* and *B* and attaching.

This simple and useful method of righting may be modified by (1) inequalities in the length of the arms, (2) injuries to certain of the arms, (3) any initial twist an arm may have due to its position before the animal was laid upon its dorsal side.

As to (1) short arms are more sluggish than ones of normal length, (2) injury to an arm inhibits the active twisting and seizing of the surface with the tube feet of this arm, (3) if an arm is partially twisted its tube feet reach the bottom more quickly than they otherwise would. As a result we have the following modifications of the normal method of righting.

1. If four arms are injured, their activity is inhibited and the righting is accomplished by the one uninjured arm. It may force an adjacent arm to coördinate weakly.

2. If *A* and *C* (Fig. 1) twist so as to face each other with their ventral surfaces, *B* receives two impulses, from opposite directions, to coördinate, and therefore does not twist either way but bends under dorsally, allowing *A* and *C* to accomplish what *A* and *B* did in the normal case. The same result may be brought about by injuring *B*, *D* and *E*.

3. Sometimes inhibitions are weak and *A*, *B*, *C* and *D* may all remain attached, *C* and *B* facing ventrally toward *A* and *D*. *E* alone is inhibited and the righting is accomplished by *A* and *B* walking backward under *C* and *D*.

I found, as Jennings noted, that in a few cases a starfish persistently refused to use a certain arm for initiating the righting movements. In most cases this was clearly due to an injury or

malformation of the inactive arm. According to the author cited, such a starfish could be "taught" to use the idle arm by giving the animal a large number of "lessons" (180 in one case) in which arms ordinarily active were prevented from taking hold by "stimulating their tube feet with a glass rod" whenever they attempted to attach themselves.

I was able to compel starfish of this sort to use the idle arm by injuring the active ones in the following ways: (1) Irritating the ventral groove of the arm by rubbing it with a glass rod, (2) treating the tips of the arm with a few drops of $n/10$ acid. Two or three applications a few minutes apart usually sufficed to render the arm inactive. In this way I was able to "teach" the starfish in one "lesson," spontaneously to use an arm previously inactive. The length of time the lesson was "remembered" depended upon the degree of the injury. It seems evident from this that Jennings' "lessons" consisted merely in inhibitions due to the injury caused by his irritating the tube feet of the active arms. But an inhibition caused by a single or persistent stimulation is not identical with the phenomena of memory manifested in the process of teaching.

Summary.

1. The righting movements of a starfish which has been placed on its dorsal side are due only to the positive stereotropism of the tube feet.

2. An injury to an arm inhibits its being used for the initiation of righting movements.

3. A starfish cannot be taught to use an arm which is ordinarily passive, but by injuring the other four arms these can be prevented from initiating righting movements and the fifth arm then initiates these movements.

I wish to express my sincere thanks to Professor Loeb for his helpful suggestions and criticism.